Surface Mooring Survivability In the Littoral Regime

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LONG-TERM GOALS

The long-term goal of this research is to develop an engineering tool that can be used to predict cyclic fatigue of the components of shallow-water moorings deployed in littoral environments.

OBJECTIVES

Research on cyclic fatigue of mooring components has shown that it is possible to quantify fatigue failure of mooring components. However, there does not exist at this time a specific design procedure or manual that can be passed on to oceanographic engineers for designing future moorings, especially those having hardware that has not been previously tested in the laboratory. The objective of this project is to develop and document a set of design procedures for shallow-water moorings that can easily be applied by oceanographic engineers to quantify fatigue damage in any type of mooring component.

APPROACH

Our approach combines full-scale experiments at the Woods Hole Oceanographic Institution (WHOI) Buoy Farm, laboratory cyclic testing of mooring components, and structural analysis using finite element methods. A full-scale test mooring will be designed with an in-line string of ½-inch chain shackles that are predicted to experience very high cyclic loading. The mooring will be deployed at the WHOI Buoy Farm during the winter storm season until one of the shackles fails. Mooring line tension will be measured throughout the deployment to document the loading history. Laboratory testing of the similar number of new ½-inch chain shackles will be used to develop probability distributions for fatigue strength. The probability distributions will be used with the measured loading history and the Palmgren-Miner damage rule to predict when a failure of the Buoy Farm mooring should have occurred. Comparison with the actual time of failure will help us develop safety factors to account for random loading and corrosion. Finite element analysis will be used to determine the spatial loading distribution on ½-inch chain shackles. Using published material properties, we will attempt to develop a theoretical technique for predicting the fatigue strength probability distributions. Finite-element analysis along with the safety factors that we calculate from the full-scale tests will serve as the basis for a cost-effective fatigue analysis method for oceanographic moorings.

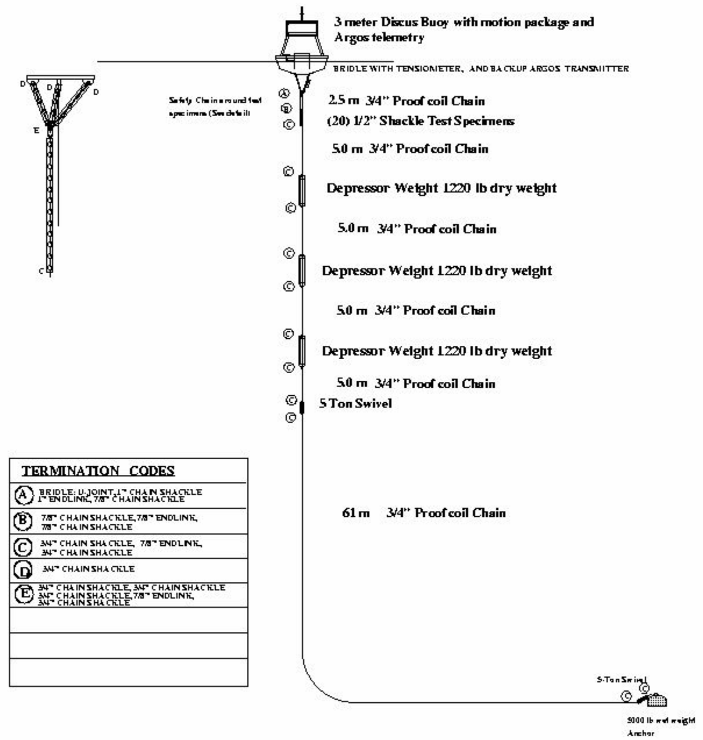

Figure 1. Surface mooring deployed at WHOI Buoy Farm

WORK COMPLETED

A surface mooring (Figure 1) with a three-meter discus buoy was deployed on October 8, 1999. The surface buoy was instrumented with a motion package and load cell. The mooring contained a string of 20 ½-inch shackles approximately three meters below the buoy bridle. To simulate a typical subsurface instrument load, three 1200-pound depressor weights were placed in line on the mooring below the test shackles. The test shackles were intentionally smaller than the conventional ¾-inch shackles normally used on such a mooring so that they would lose a significant percentage of their fatigue life over the course of the winter deployment. A safety chain paralleled the test specimens. As planned, one of the ½-inch shackles failed after 125 days. Though this is a single data point, it provides an actual mooring component failure along with the complete load history.

Laboratory hardware testing of ½-inch and ¾-inch shackles has been completed. The most significant tests from the past year, where high-cycle, low-stress tests on new and used ½-inch shackles. The used shackles were the unbroken samples from the Buoy Farm mooring. We also did low-cycle, high-stress tests on new ½-inch shackles. The tests on the new hardware will be used to develop probability distributions for the fatigue strength of the ½-inch shackle, which will be used to analyze the full-scale results. The laboratory data will also be used to verify finite element procedures for predicting fatigue properties of different shaped mooring components.

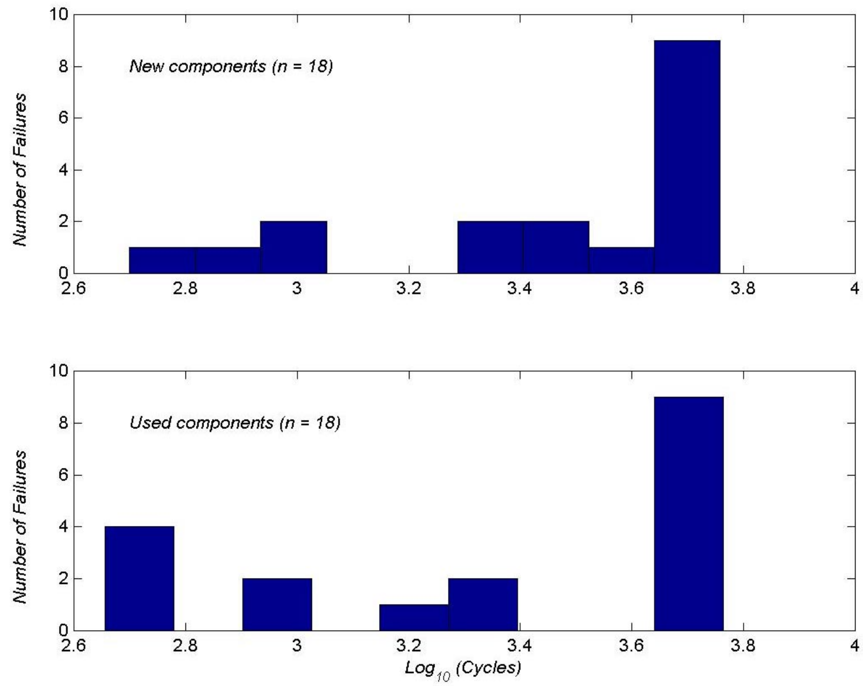

Figure 2. Histograms showing number of failures that occurred during laboratory fatigue tests involving new and used ½-inch shackles. The used shackles had been deployed for 125 days on an engineering test mooring at the WHOI Buoy Farm.

RESULTS

Figure 2 shows the results from the high-cycle, low-stress tests on new and used ½-inch shackles. Each series of tests involved n=18 components. The load range for these tests was 3,000-5,000 lbs, which was a typical load range seen by the full-scale mooring during rough weather. As reference, the mean ultimate strength of 11 new ½-inch shackles was measured to be 41,200 lbs with a standard deviation of 1,900 lbs. Tests on each part were suspended after 5×10^6 cycles if no failure had occurred. In both cases (new and used tests), there was a group of parts that failed after less than 5×10^6 cycles and a second group (containing an equal number of parts) that never failed. Of the parts that failed, there appears to be a difference in fatigue resistance between the new and used components. The difference is due to the fatigue damage experienced by the used parts during the Buoy Farm deployment. The used parts experienced over 1×10^6 cycles though most were of smaller amplitude than that used in the laboratory tests.

The data in Figure 2 indicates that a fracture mechanics approach to the data analysis is needed. We believe that the group of parts that failed during the laboratory tests and during the full-scale deployment contained initial flaws larger than a critical value (perhaps associated with the galvanizing process). In the case of the used parts, the flaws grew in response to the loading experience during the full-scale deployment. For one part on the Buoy Farm mooring, the flaw reached a length that caused failure. For the other used parts that were recovered, crack growth resulted in components with less fatigue resistance then new parts. The key is that we can quantify through statistical analysis, this difference. We are presently applying survival statistical methods to the data to complete this analysis. Another important point that the data shows is how a small cyclic load, which is only 7-12% of the ultimate load, can produce fatigue failures.

IMPACT/APPLICATIONS

At the end of the research we will have a comprehensive design procedure for analyzing the fatigue characteristics of shallow-water oceanographic moorings. The design procedure will be the link between *WHOI Cable* software for predicting tensions in moored instrument strings and final designs of moorings that oceanographers can confidently deploy for long periods of time.

TRANSITIONS

The design procedure will be documented in a WHOI blue-cover report, which will serve as a design manual that engineers can use to predict survivability of oceanographic surface moorings.

RELATED PROJECTS

The dynamic analysis of the surface mooring and the predictions of long-term statistics of the dynamic tensions acting on the test components was performed with numerical codes and analytical models developed as part of the project *Understanding the Dynamics of Shallow-Water Oceanographic Moorings* (ONR Award # N00014-92-J-1269 Ocean Engineering and Marine Systems Program Code 321OE).